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Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Page 2 de l'attestation

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"scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO97/33205, for example.

Until very recently, lithographic apparatus contained a single mask table and a single substrate table. However, machines are now becoming available in which there are at least two independently moveable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO98/28665 and WO98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is at the exposure position underneath the projection system for exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge a previously exposed substrate, pick up a new substrate, perform some initial measurements on the new substrate and then stand ready to transfer the new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed; the cycle then repeats. In this manner it is possible to increase substantially the machine throughput, which in turn improves the cost of ownership of the machine. It should be understood that the same principle could be used with just one substrate table which is moved between exposure and measurement positions.

A very important criterion in semiconductor manufactures is the accuracy with which the successive layers printed on the substrate are aligned with each other. Mis-alignments of the whole or part of an exposure or series of exposures, referred to as overlay errors, for all the many layers required to make an integrated circuit must be kept within tight limits for the resulting device to function correctly. To correctly align the substrate to the mask, alignment marks, which generally take the form of diffraction gratings are etched in the bare silicon substrate. These alignment marks (referred to as "zero marks") are aligned to corresponding marks provided on the mask using a variety of techniques, including through the lens (TTL) alignment systems and off-axis alignment systems. An example of the latter is described in EP-A-0 906 590 (P-0070). However, once a few process layers have been deposited or grown on the substrate, the zero marks etched in the bare substrate often become obscured and are no longer visible to the radiation used in the alignment process. Even if not completely obscured, the growth of layers on top of the alignment marks can be uneven, leading to a shift in the apparent position of the alignment mark. To enable alignment after the zero marks have been obscured, further alignment marks are printed during the deposition of suitable layers of the device. The subsequent marks, referred to as non-zero marks, are however subject to damage during

Alignment in Lithographic Projection Apparatus

The present invention relates to the alignment of the substrate in a lithographic projection apparatus after some process layers have been deposited. More particularly, the invention relates to an alignment system in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a first object holder for holding a mask;

a second object table provided with a second object holder for holding a substrate; and

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto an exposure area (die) on a substrate (silicon wafer) which has been coated with a layer of energy-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated via the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the

subsequent process steps and will also accumulate overlay errors from previous process layers. When etching a blanket aluminum layer to define the interconnects of the integrated circuit, it is preferred to align to the original zero marks but to do this requires that the overlying aluminum layers, and possibly also dielectric layers, be removed. Such clearout steps are undesirable.

A technique known as Impulsive Stimulated Thermal Scattering (ISTS) for measuring acoustic and thermal film properties, such as elastic constants and thermal diffusion rates, has been described in various publications such as J.A. Rogers et al., Appl. Phys. Lett **71** (2), 1997; A.R. Duggal et al. J. Appl. Phys. **72** (7), 1992; R. Logan et al., Mat. Res. Soc. Symp. Proc. **440**, pg 347, 1997; L Dhar et al., J. Appl. Phys. **77** (9), 1995; and J.A. Rogers et al. Physica B 219 & 220, 1996. In this method, two excitation pulses overlapping in time and space are incident on a sample at slightly different angles. The two pulses interfere and heat the sample in a pattern corresponding to the interference pattern between them. The local heating sets up vibrations in the crystal structure of the sample which act as a diffraction grating to a probe pulse incident on the sample shortly after the excitation pulses. The diffraction of the excitation pulse is measured to give an indication of the property being investigated in the sample.

An object of the present invention is to provide an alignment system capable of alignment to alignment marks, e.g. formed directly in or on the substrate surface, even after they have been concealed by subsequent process steps.

According to the present invention there is provided a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a first object holder for holding a mask;

a second object table provided with a second object holder for holding a substrate; and

a projection system for imaging an irradiated portion of said mask onto a target portion of said substrate; characterized by:

an excitation source for directing excitation electromagnetic radiation to said substrate so as to induce an acoustic wave therein in a region of an at least partially buried substrate alignment mark; and

an alignment system for directing a measurement beam to be reflected by said substrate and for detecting reflectivity changes in said substrate caused by said acoustic wave thereby to perform an alignment to said substrate alignment mark.

The present invention uses acoustic waves induced in the process layers covering, or partially covering, a substrate alignment mark to reveal its true position. The substrate alignment

mark may be one provided in or on the substrate itself or a deposited process layer. It thereby allows accurate alignment for critical process steps late in a manufacturing procedure, without accumulating overlay errors from earlier steps and without the need for clearout steps. The acoustic waves cause reflectivity changes in the surface whose position and/or time dependence reveals the true position of the buried substrate alignment mark. The buried substrate alignment mark may be revealed by mapping the thickness of covering layers in its vicinity, e.g. by measuring the time dependence of the decay of a standing wave induced in the covering layers or by measuring the delay time of echoes of a travelling wave created at interfaces between different ones of the covering layers. Alternatively, a travelling wavefront can be created over the whole area of the mark so that echoes off the top and bottom of the buried mark carry positive and negative images of the mark; these cause reflectivity differences when they reach the surface which can be aligned to.

According to a further aspect of the present invention there is provided a method of alignment in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a first object holder for holding a mask; and

a second object table provided with a second object holder for holding a substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table; and

providing a substrate having a radiation-sensitive layer to said second object table; characterized by the steps of:

inducing an acoustic wave in surface layers of said substrate at least partially covering a substrate alignment mark;

measuring the reflectivity of the surface of said substrate where said acoustic wave has been induced; and

aligning said substrate alignment mark to a corresponding mask alignment mark using the results of said step of measuring the reflectivity.

The present invention also provides a method of manufacturing a device comprising the steps of the method described above and the further step of imaging irradiated portions of the mask onto target portions of the substrate.

In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate

may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices (dies) will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "exposure area", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. at a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm), extreme ultraviolet radiation (EUV), X-rays, electrons and ions. Also herein, the invention is described using a reference system of orthogonal X, Y and Z directions and rotation about an axis parallel to the *I* direction is denoted R*i*. Further, unless the context otherwise requires, the term "vertical" (Z) used herein is intended to refer to the direction normal to the substrate or mask surface, rather than implying any particular orientation of the apparatus.

The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 depicts a zero mark on a wafer covered by an aluminum layer illustrating PVD induced alignment shift;

Figure 3 is a view used in explaining the cause of PVD induced alignment shift;

Figure 4 depicts laser-induced surface gratings used in the first embodiment of the invention;

Figure 5 depicts a zero mark on a wafer covered by an aluminum layer illustrating PVD induced alignment shift and the corresponding layer thicknesses;

Figures 6A to 6D illustrate a thickness measurement technique used in a second embodiment of the invention; and

Figures 7A to 7E illustrate the procedure for revealing a buried mark of a third embodiment of the invention.

In the drawings, like references indicate like parts.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, Ex, IN, CO for supplying a projection beam PB of radiation (e.g. UV or EUV radiation);
- a first object table (mask table) MT provided with a mask, or first object, holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate or wafer table) WT provided with a substrate, or second object, holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto an exposure area C (die) of a substrate W held in the substrate table WT.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

The radiation system comprises a source LA (e.g. a Hg lamp, excimer laser, an undulator provided around the path of an electron beam in a storage ring or synchrotron, a laser plasma source or an electron or ion beam source) which produces a beam of radiation. This beam is passed along various optical components comprised in the illumination system — e.g.

beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having passed through the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto an exposure area C of the substrate W. With the aid of the interferometric displacement measuring means IF, the substrate table WT can be moved accurately by the second positioning means, e.g. so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus) the reticle table may be connected only to a short-stroke positioning device, to make fine adjustments in mask orientation and position.

The depicted apparatus can be used in two different modes:

1. In step-and-repeat (step) mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto an exposure area C. The substrate table WT is then shifted in the X and/or Y directions so that a different exposure area C can be irradiated by the beam PB;

2. In step-and-scan (scan) mode, essentially the same scenario applies, except that a given exposure area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large exposure area C can be exposed, without having to compromise on resolution.

Figure 2 shows a zero mark M0 etched in the substrate of wafer W and covered by an aluminum layer Al. If, as illustrated, the aluminum layer has been deposited at an angle on the zero mark M0, the center of the aluminum-covered mark is shifted relative to the center of the underlying zero mark M0 by an amount d. An alignment sensor effectively detects the position of the center of the mark and so will give a position shifted from the true position by an amount d. Where the mark is a grating, an alignment sensor effectively measures the average position of all the lines in the grating. However, since all the grating lines are close together, they will all

have a similarly shifted aluminum deposition and so the average position will suffer from the same shift.

A probable cause of asymmetric aluminum deposition in Physical Vapor Deposition (PVD) is shown in Figure 3 in relation to a mark M0 near the edge of the wafer. In PVD, the aluminum layer grows by accretion of aluminum particles. As each particle is deposited, the layer will grow in the direction of incidence of that particle. Since the layer is built up from many particles, the net direction of growth of the layer will be related to the average direction of incidence of the particles making up the layer. As can be seen from Figure 3, the average angle of incidence of particles on a mark M0 near the edge of the wafer will be an angle A1, which is somewhat inclined to the vertical, whereas the average angle of incidence A2 of particles on a mark M0' near the center of the wafer will be vertical or nearly so. Thus aluminum will grow on mark M0 at an angle toward the center of the wafer, resulting in an effective shift of the mark.

In the first embodiment of the invention, the thickness of the aluminum layer across the width of the mark is measured using an impulsive stimulated thermal scattering (ISTS) technique. This is illustrated in Figure 4. Two excitation pulses EP are emitted by excitation source 11 and directed so as to be co-incident simultaneously on the wafer surface at a small angle a to the normal. The two excitation pulses EP are of sub-nanosecond duration, e.g. 400ps, and excitation source 11 may be a passively Q-switched, single mode, Nd YAG microchip laser pumped by a 1.2 W Diode laser. The excitation pulse wavelength may be 1064nm, for example. Suitable laser sources are described in J.J. Zayhowski, Laser Focus World, April 1996 pp 73-78, which document is incorporated herein by reference. In the film (aluminum layer), thermal expansion induced by the local heating of the film where the two excitation pulses constructively interfere induces acoustic and thermal responses, leading to the formation of a thermal grating. The acoustic waves are counter-propagating and damped so the thermal waves forming the grating are quasi-steady state material responses and persist until the thermal diffusion washes out.

Whilst the thermal grating persists, a probe pulse P is emitted by probe source 12, at a relatively large angle to the normal, so as to be diffracted by the thermal grating. The amount of diffraction of the probe pulse P is detected by detector 13, which allows the state of the thermal diffraction grating to be monitored in real time. The probe source 12 may be an 860nm diode laser operating in a quasi-continuous wave mode. The detector, and data recording/processing electronics have a nanosecond time resolution.

The excitation region is typically 25μm x 500μm whilst the probe spot can be circular with 20μm diameter, allowing several measurements to be taken from one excitation.

The fringe spacing of the induced grating depends only on the wavelength of the excitation pulses and the crossing angle *a*. The film acts as an acoustic waveguide, supporting waveguide modes whose displacements include both shear and compression. Each mode has a characteristic dispersion relation giving the acoustic velocity as a function of wave vector. Each mode has the same dependence on the wave vector and the film thickness; the dispersion relation is determined by the elastic modulus and density of the film and the underlying substrate. Since the properties of the, e.g. AlCu, film are known, in the invention, the time-dependent diffraction of the probe beam can be used to determine the acoustic frequency and hence film thickness.

A plurality of spaced apart film thickness measurements are taken along a line bisecting the alignment mark. As shown in Figure 5, the thickness profile of the Al layer will show one thinner region, t1, and one thicker region, t2, either side of the zero mark M0. The thinner and thicker regions t1, t2 correspond to the Al deposits on zero mark M0 and their width will indicate the apparent alignment shift observed when aligning to the obscured mark. The determined widths can be used to correct an alignment carried out to the surface appearance of the mark.

Embodiment 2

In a second embodiment of the invention a different method is used to measure the film thicknesses, but otherwise the same principles apply. This method is illustrated in Figures 6A to 6D.

Figure 6A shows pump source 21, which may be a TiS laser for example and emits ultra short excitation pulses, for example pulses of 150fs duration at a frequency of 80MHz, which are directed onto the wafer where they instantaneously heat the surface of the uppermost layer L1 on the wafer at spot HS. The heating of the surface creates a sound wave S which propagates downwards into the layers L1, etc, deposited on the wafer substrate W, as shown in Figure 6B. Meanwhile, detection beam source 22 directs detection beam DB onto the wafer surface where it is reflected to detector 23, whose output is a measure of the reflectivity of the surface of layer L1. The detection beam DB may be a delayed portion of the excitation pulses EP or may be generated by a separate source.

When the sound wave S reaches the first interface in the stack, between layers L1 and L2, a portion of the energy will be reflected back towards the surface, shown as echo E1 in Figure 6C, whilst the attenuated sound wave S continues downwards. The proportion of energy

reflected will depend on the acoustic impedances of the two layers. When echo E1 reaches the upper surface of the top layer L1 as shown in Figure 6D, it will cause a change in the reflectivity of that surface which is detected by detector 23. The sign and magnitude of the reflectivity change will depend on the two materials meeting at the interface and factors such as the roughness of the interface (the local crystal structure). Of course, as the sound wave S propagates further down the layers deposited on the wafer, other echoes will be generated. Figure 6D also shows echo E2 generated at the interface between layers L2 and L3.

The timing of the reflectivity changes is dependent on the speed of sound in the layers and the layer thicknesses; since the former are known the later can be calculated quite simply.

In variations of the second embodiment, the reflectivity data can be deconvolved to compensate for a relatively large spot size, and the spot size can be reduced using a second grating to blade part of the mark structure.

Embodiment 3

In a third embodiment of the invention, the buried mark is acoustically revealed on the surface of the covering layers and can then be directly aligned to. The procedure for this is shown in Figure 7A to 7B.

Firstly, the outer surface OS of the deposited layer or layers covering the mark M is excited using a short pulse laser, for example of the type described above, over the whole area of the buried mark M. This generates an acoustic wavefront WF which propagates downwards through the covering layers, as shown in Figure 7A. When the wavefront WF meets the level of the top of the buried mark M, as shown in Figure 7B, reflections will be generated only in the areas where the mark is raised. Thus the first reflection R1 which returns towards the outer surface OS will carry an image of the buried mark. The remainder of the wavefront WF continues to propagate downwards in the etched area of the mark M. This is the situation shown in Figure 7C.

When the first reflection R1 reaches the outer surface OS, as shown in Figure 7D, the surface will be excited in a pattern corresponding to the buried mark M. The difference in reflectivity between the excited and unexcited areas of the surface forms a diffraction grating which diffracts the alignment beam in the same way as the mark M itself. An alignment can then be carried out to the acoustic representation of the buried mark M.

A second alignment is also possible using the second reflection R2. This is reflected by the etched away portions of the mark M and reaches the outer surface OS a short time after the

first reflection R1. The time delay will depend on the depth of mark M and the speed of sound in the covering layers. Figure 7E shows how the second reflection excites the outer surface OS in a grating pattern that is the negative of the mark M but can be aligned to in a similar manner.

Of course, the excitation and alignment process can be repeated as often as required to complete an alignment process to the desired accuracy.

In a variation of the third embodiment, the femtosecond laser used to excite the acoustic travelling wave in the layer(s) covering the buried mark is replaced by a less-expensive amplitude-modulated (semi-)continuous laser. The amplitude modulation of the continuous laser is arranged so as to periodically excite the surface layer in-phase with the returning acoustic waves from the spaces of the buried mark and 180° out of phase with the acoustic wave returning from the lines of the buried mark and from the bulk material. The acoustic projection of the mark on the surface, defined by reflectivity changes, then has a good contrast and can be aligned to easily.

In the case of a mark buried at a depth of 120nm in material with a speed of sound of 2.4km/s, the modulation frequency is of the order of $(2.4 \times 10^3 / 240 \times 10^{-9})$Hz = 10GHz. This can easily be achieved with electro-optical modulators which can be tuned as appropriate for different depths of the buried mark and different covering materials.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention. In particular, it will be appreciated that whilst the invention has been described in terms of alignment to buried zero marks, it can of course be used in alignment to any buried mark or feature.

CLAIMS

1. A lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a first object holder for holding a mask;

a second object table provided with a second object holder for holding a substrate; and

a projection system for imaging an irradiated portion of said mask onto a target portion of said substrate; characterized by:

an excitation source for directing excitation electromagnetic radiation to said substrate so as to induce an acoustic wave therein in a region of an at least partially buried substrate alignment mark; and

an alignment system for directing a measurement beam to be reflected by said substrate and for detecting reflectivity changes in said substrate caused by said acoustic wave thereby to perform an alignment to said substrate alignment mark.

2. Apparatus according to claim 1 wherein:

said excitation system is arranged to induce acoustic waves in said substrate at a plurality of points; and

said alignment system is arranged to detect reflectivity changes at said plurality of points to generate thickness data relating to thicknesses of at least one layer covering said substrate alignment mark and to correct an alignment process carried out using a surface pattern induced by said substrate alignment mark.

3. Apparatus according to claim 2 wherein said excitation source is arranged to irradiate a measurement area with two temporally coincident overlapping excitation pulses having mutually different angles of incidence, thereby to induce an acoustic standing wave pattern in the surface of said substrate; and said alignment system comprises a measurement beam source for directing a measurement beam to be diffracted by said standing wave pattern and a detector for detecting the time-dependent diffraction of said measurement beam.

4. Apparatus according to claim 2 wherein said excitation source is arranged to irradiate a measurement area with an excitation pulse or pulse train so as to generate an acoustic travelling wave propagating into said substrate; and said alignment system comprises a measurement beam source for directing a measurement beam to be reflected by the surface of said substrate and a

detector for detecting time-dependent changes in the reflectivity of said surface of said substrate caused by returning echoes of said travelling wave.

5. Apparatus according to claim 1 wherein said excitation source is arranged to irradiate said region so as to induce an acoustic travelling wave front in at least one covering layer obscuring said substrate alignment mark so as to be selectively reflected by said substrate alignment mark; and said alignment system comprises an alignment beam source for directing an alignment beam to be diffracted by positive and/or negative images of said substrate alignment mark formed in the surface of said covering layer by returning echoes of said substrate alignment mark.

6. A method of alignment in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a first object holder for holding a mask; and

a second object table provided with a second object holder for holding a substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table; and

providing a substrate having a radiation-sensitive layer to said second object table;

characterized by the steps of:

inducing an acoustic wave in surface layers of said substrate at least partially covering a substrate alignment mark;

measuring the reflectivity of the surface of said substrate where said acoustic wave has been induced; and

aligning said substrate alignment mark to a corresponding mask alignment mark using the results of said step of measuring the reflectivity.

7. A method according to claim 6 wherein said steps of inducing an acoustic wave and measuring the reflectivity are repeated at a plurality of spaced apart positions in the region of said substrate alignment mark so as to generate a map of the thickness of at least one layer covering said substrate alignment mark and said map is used in said step of aligning to correct an alignment process carried out using the surface pattern induced by said substrate alignment mark.

8 A method according to claim 7 wherein said step of inducing an acoustic wave comprises irradiating a measurement area with two temporally coincident overlapping excitation

pulses having mutually different angles of incidence, thereby to induce an acoustic standing wave pattern in the surface of said substrate; and said step of measuring comprises measuring the time-dependent diffraction of a measurement beam by said standing wave pattern and calculating the thickness of at least one layer covering the substrate alignment mark using the measured time-dependent diffraction.

9. A method according to claim 7 wherein said step of inducing an acoustic wave comprises irradiating a measurement area with an excitation pulse or pulse train so as to generate an acoustic travelling wave propagating into said substrate; and said step of measuring comprises directing a measurement beam to be reflected by the surface of said substrate, detecting time-dependent changes in the reflectivity of said surface of said substrate caused by returning echoes of said travelling wave and calculating the thickness of at least one layer covering said substrate alignment mark from the time of occurrence of reflectivity changes caused by said returning echoes.

10. A method according to claim 6 wherein said step of inducing an acoustic wave comprises irradiating a region encompassing said substrate alignment mark so as to induce an acoustic travelling wave front in at least one covering layer obscuring said substrate alignment mark so as to be selectively reflected thereby, and said steps of measuring and aligning comprise directing an alignment beam to be diffracted by reflectivity differences in said surface containing positive and/or negative images of said substrate alignment mark formed in the surface of said covering layer by returning echoes of said substrate alignment mark.

11. A method of manufacturing a device comprising the steps of any one of claims 6 to 10 and the further step of imaging irradiated portions of the mask onto target portions of the substrate.

12. A device manufactured according to the method of claim 11.

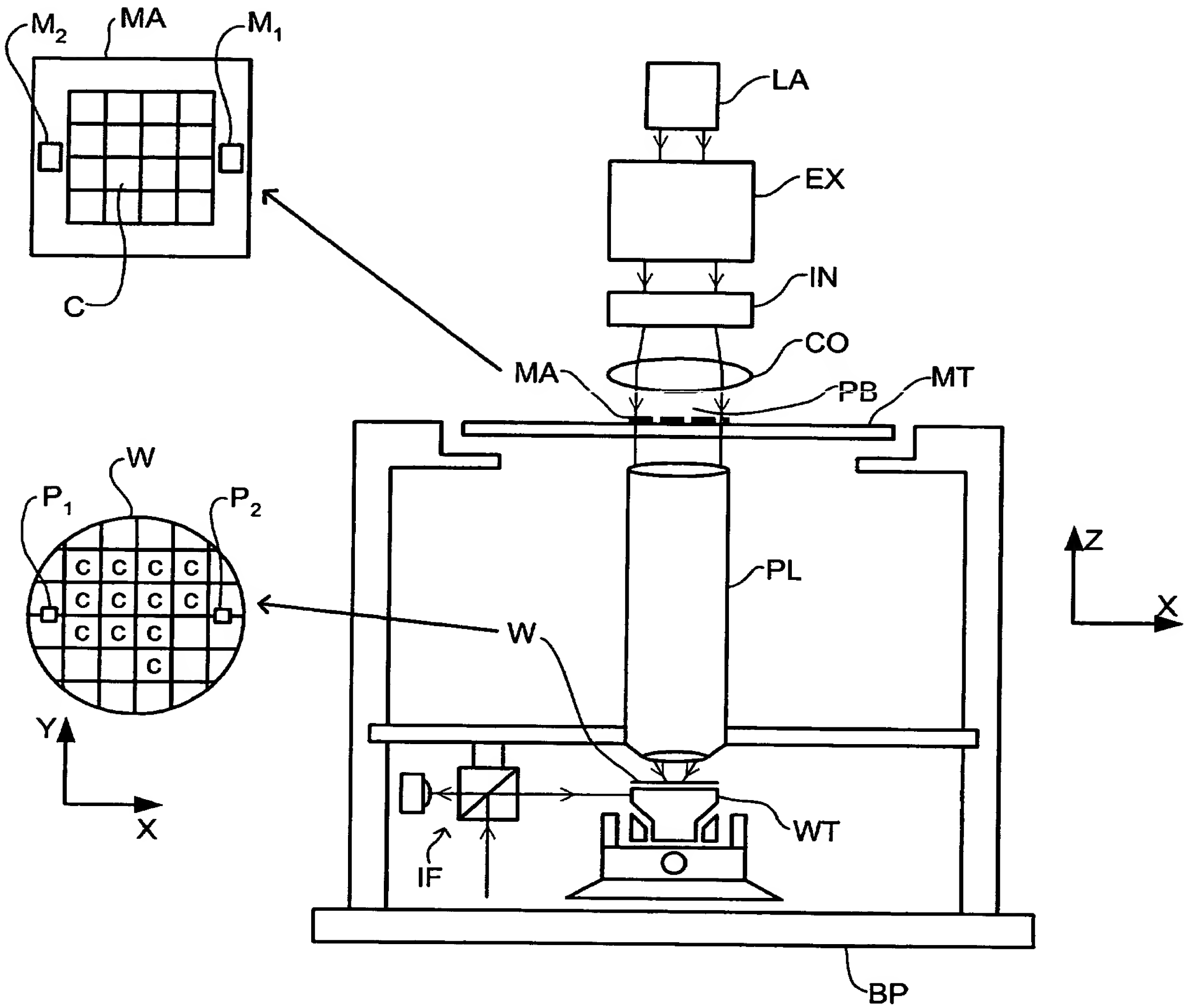
ABSTRACT

Alignment in Lithographic Projection Apparatus

Alignment to buried marks is carried out by using electromagnetic radiation to induce acoustic waves in the layers covering the buried layer. The acoustic waves cause reflectivity changes in the surface whose position and/or time dependence reveals the true position of the buried alignment mark. The buried alignment mark may be revealed by mapping the thickness of covering layers in its vicinity, e.g. by measuring the time dependence of the decay of a standing wave induced in the covering layers or by measuring the delay time of echoes of a travelling wave created at interfaces between different ones of the covering layers. Alternatively, a travelling wavefront can be created over the whole area of the mark so that echoes off the top and bottom of the buried mark carry positive and negative images of the mark; these cause reflectivity differences when they reach the surface which can be aligned to.

Fig. 4

Fig. 1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M1
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LA
EX
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MA
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W
P1
P2
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c c c c
c c c
c
PL
Z
X
W
Y
X
WT
IF
BP

P-0181

FIG. 2

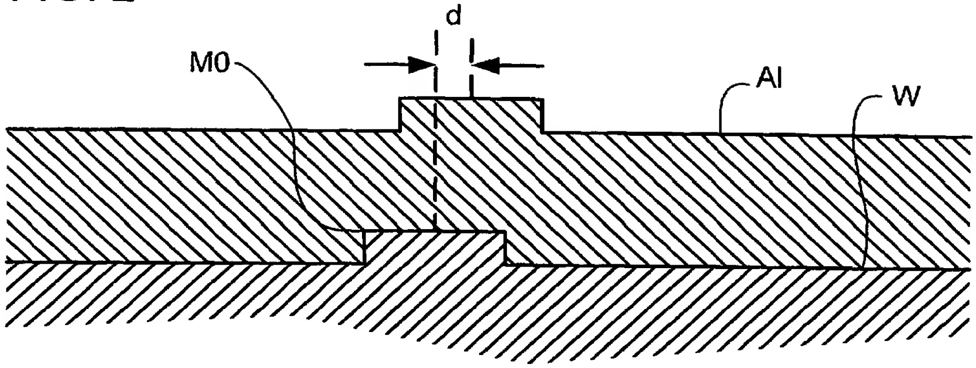


FIG. 3

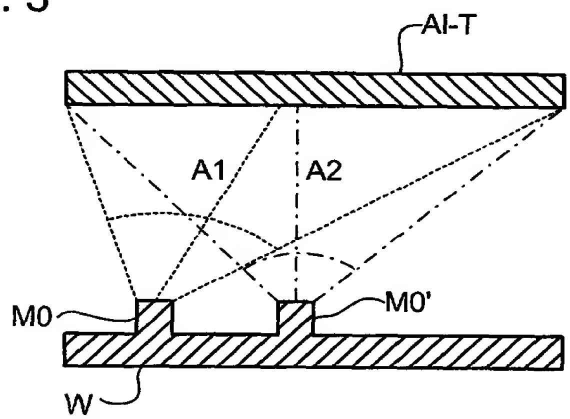
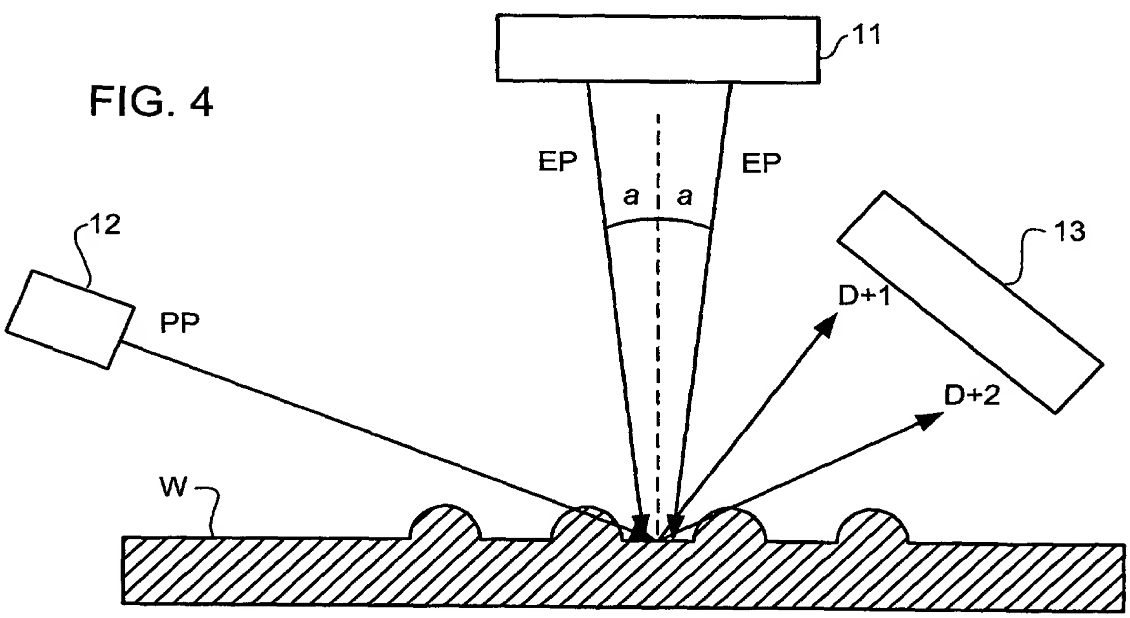


FIG. 4



P-0181

FIG. 5

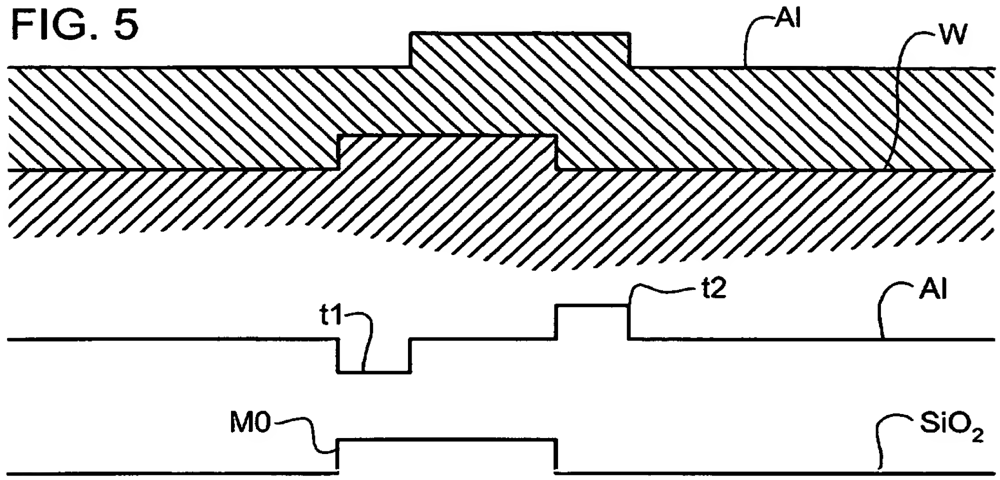


FIG. 6A

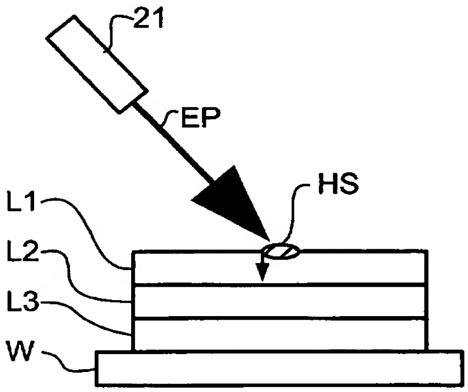


FIG. 6B

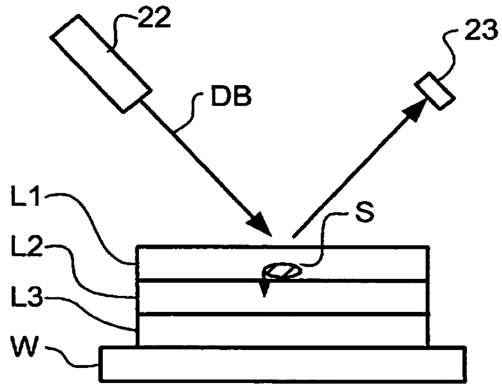


FIG. 6C

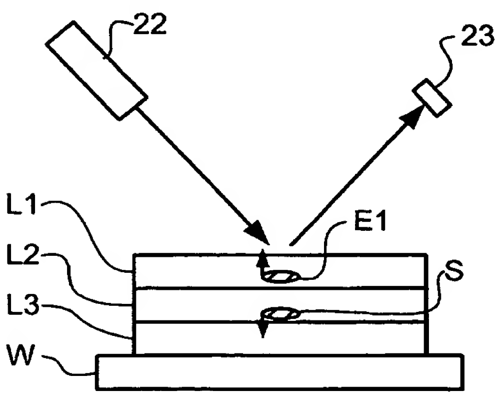


FIG. 6D

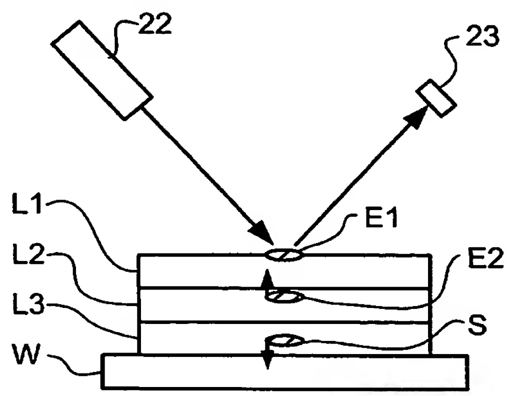


FIG. 7A

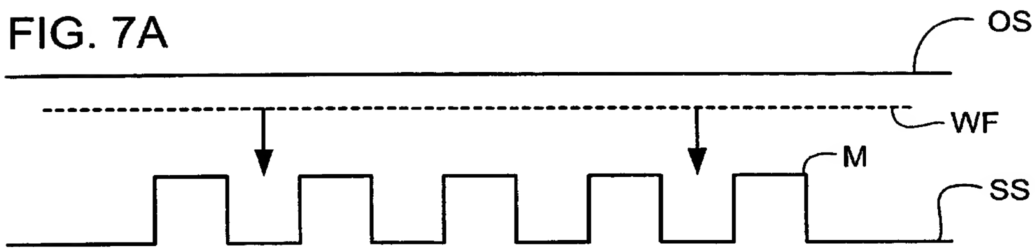


FIG. 7B

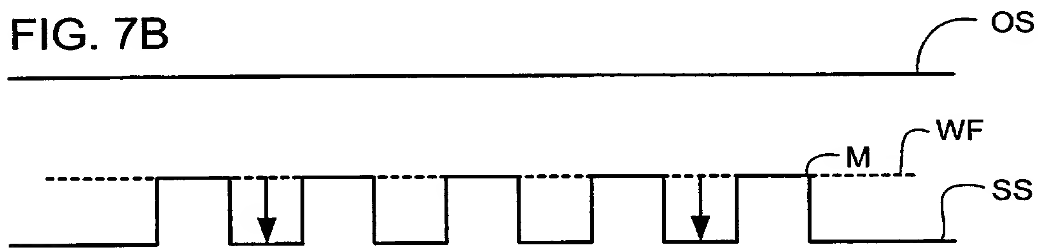


FIG. 7C

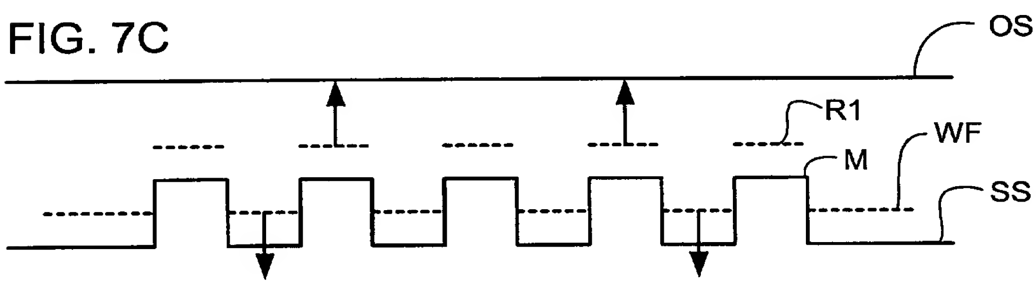


FIG. 7D

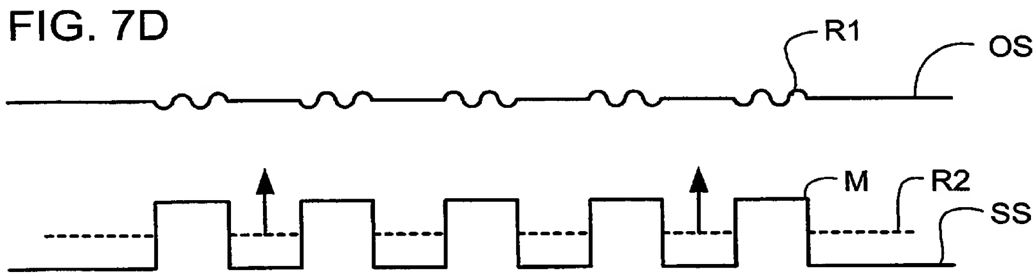


FIG. 7E